

# DISCOVERY OF THE DISTURBED RADIO MORPHOLOGY IN THE INTERACTING BINARY QUASAR FIRST J164311.3+315618

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## ABSTRACT

We report the high resolution radio observations and their analysis of a radio-loud compact steep spectrum (CSS) quasar FIRST J164311.3+315618, one of the members of a binary system. The second component of the system is a radio-quiet AGN. The projected separation of this pair is  $2.3''$  (15 kpc) and it is one of the known smallest separation binary quasars. The multi-band images of this binary system made with the Hubble Space Telescope showed that the host galaxy of the radio-loud quasar is highly disturbed. The radio observations presented here were made with the multi-element radio linked interferometer network (MERLIN) at 1.66 GHz and 5 GHz. We show that the radio morphology of FIRST J164311.3+315618 is complex on both frequencies and exhibits four components, which indicate on the intermittent activity with a possible rapid change of the jet direction and/or restart of the jet due to the interaction with the companion. The radio components that are no longer powered by the jet can quickly fade away. We suggest that this makes the potential distortions of the radio structure to be short-lived phenomena. On the other hand, our numerical simulations show that the influence of the companion can lead to the prolonged current and future activity. FIRST J164311.3+315618 is an unusual and statistically very rare low redshift binary quasar in which probably the first close encounter is just taking place.

*Subject headings:* black hole physics – galaxies: active – galaxies: evolution – galaxies: interactions

## 1. INTRODUCTION

It has been established that most galaxies host a super-massive black hole (Magorrian et al. 1998), and the next open issue is the mechanism that triggers gas accretion and nuclear activity. It is likely that active galactic nuclei can pass through subsequent stages of higher and lower activity. Intermittent behavior of this type can be caused by minor mergers or instabilities in the accretion flow. On long timescales, up to  $10^8$  years, the merger activity is broadly considered as the cause of an enhanced accretion flow and the main provider of material for the black hole growth (Barnes & Hernquist 1996; Volonteri et al. 2003; Di Matteo et al. 2005).

Close binary QSOs presumably represent a very early stage of a merger of galaxies. The merger will likely produce a supermassive binary black hole (Begelman et al. 1980). Based on optical surveys, only about 0.1% of all quasars observed have one, or more, nearby quasar companion at the same redshift (e.g. Kochanek et al. 1999; Hewett et al. 1995; Foreman et al. 2009). These may either be gravitational lenses, true quasar pairs, or chance alignments. Arguments weighted after of binary quasar classification are: lack of a detectable lens, different quasar spectra and/or properties like the case when one object is radio-quiet and the other radio-loud. There is a growing number of identifications of physical pairs of quasars or as good candidates (Kochanek et al. 1999; Hennawi et al. 2010; Liu et al. 2010). Among them the highest-redshift binary known LBQS 0015+0239 at

$z=2.45$  (Impey et al. 2002), LBQS 1429-0053 (Faure et al. 2003) and UM 425 (Mathur & Williams 2003; Aldcroft & Green 2003) with similar optical spectra but lack of a candidate lensing system, and Q 2345+007 (Green et al. 2002) with different optical and X-ray spectra but no lens candidate found in optical and X-ray band. The smallest-separation known binaries are LBQS 0103-2753 (Junkkarinen et al. 2001) with separation  $0.3''$  and very recently discovered SDSS J1536+0441 (Borson & Lauer 2009; Decarli et al. 2009) with separation  $1''$ . While most of the binaries are  $O^2$  pairs (both quasars are radio faint), there are four known  $O^2R$  systems (one quasar is radio-loud, and the other is radio-quiet): PKS 1145-071 (Djorgovski et al. 1987), MGC 2214+3550 (Munoz et al. 1998), Q1343+2640 (Crampton et al. 1988), and FIRST J164311.3+315618 (Brotherton et al. 1999) studied in the present paper. The existence of two images with extremely different flux ratios in the optical and the radio strongly favors the binary quasar classification.

Most of the binaries are high redshift objects with separation  $3''$ - $10''$ , which corresponds to distances of  $\sim 10 - 80$  kpc (Mortlock et al. 1999). According to Junkkarinen et al. (2001) the observed  $3''$ - $10''$  binary QSOs mostly represent galaxy pairs undergoing the loop following the first close encounter. The still open question is if the host galaxies of the binary quasars interact in the process of merging. If so, we should observe morphological and kinematical distortions in these systems and their character should depend on the evolutionary stage of the pair. In the late phase of their encounter we might expect compact, morphologically highly disturbed system with a pair of active supermassive black holes

at its center. A few binary supermassive black holes have been observed so far: NGC 6240 (Komossa et al. 2003), Arp 299 (Ballo et al. 2004), 0402+379 (Rodriguez et al. 2006) and COSMOS J100043.15+020637.2 (Comerford et al. 2009), and cluster members 3C75 (Owen et al. 1985) and J0321-455 (Klamer et al. 2004). Strong evidence for the interaction of the host galaxies of the binary AGN system SDSS J1254+0846 (separation  $3.8''$ ) has been provided through the observed distortion of the optical light from one of the host galaxies, showing obvious tidal tails (Green et al. 2010). Here we report that radio-loud/radio-quiet binary quasar system associated with the radio source FIRST J164311.3+315618 (hereafter FIRST J1643+3156) shows disturbed radio morphology possibly indicating that the two quasars are in the process of merging. The distortions of the host galaxy of the radio-loud quasar of this system have been also discovered (Martel et al. 2005).

The radio-loud/radio-quiet binary quasar associated with the radio source FIRST J1643+3156 has been classified by Brotherton et al. (1999) based on the optical observations. It is a small separation,  $2.3''$  (15 kpc), quasar pair with redshift  $z = 0.586$  and greatly discrepant optical and radio flux ratios ( $O^2R$  pairs). On this basis the gravitational lens hypothesis has been ruled out (Brotherton et al. 1999). The radio-loud component of this pair is characterized by strong, narrow emission line spectrum and X-ray emission. In the radio-quiet one the starburst has been triggered (Brotherton et al. 1999). There is a very small difference in the quasars' redshifts:  $z = 0.5867$  for radio-loud component, and  $z = 0.5862$  for radio-quiet component. A crosscorrelation analysis indicates that radio-loud source is redshifted relative to the radio-quiet one by the order of  $V = 300 \text{ km s}^{-1}$  (Brotherton et al. 1999). The radio emission of the radio-quiet component is undetected. The radio-loud component of the binary quasar, FIRST J1643+3156, is a Compact Steep Spectrum (CSS) radio source with spectral index  $\alpha_{1.4\text{GHz}}^{4.85\text{GHz}} = 0.82$ . It has a total flux density of  $S_{1.4\text{GHz}} = 113 \text{ mJy}$ , what gives the moderate luminosity of  $\log L_{1.4\text{GHz}} = 26.20 \text{ W Hz}^{-1}$ . The black hole mass of the radio-loud component has been estimated (Shen et al. 2010) to be  $M_{\text{BH}} = 3 \times 10^8 M_{\odot}$ , the bolometric luminosity assumes  $\log L_{\text{bol}} = 45.736 \text{ erg s}^{-1}$ , and the Eddington ratio is  $L_{\text{bol}}/L_{\text{Edd}} = 0.16$  (Table 1).

In this paper we present high resolution radio observations of the radio-loud component of the binary system and their analysis. The observations were made with the multi-element radio linked interferometer network (MERLIN) at 1.66 GHz and 5 GHz. The unusual complex morphology of FIRST J1643+3156 is discussed as the consequence of the quasars interaction and/or the restart of the activity of the radio-loud one.

## 2. RADIO OBSERVATIONS

The binary quasar FIRST J1643+3156 belongs to the sample of 44 Low Luminosity Compact (LLC) objects we observed and analyzed in Kunert-Bajraszewska et al. (2010a). The snapshot 1.66 GHz and 5 GHz MERLIN observations of the FIRST J1643+3156 were undertaken in 2007 and 2009. The target source together with its associated phase reference source was observed for  $\sim 60$  min including telescope drive times. The initial data reduction of raw MERLIN data was made us-

TABLE 1  
BASIC PARAMETERS OF FIRST J1643+3156

Parameter	Value	Ref
Other source name (B1950)	1641+320	
RA (J2000) extracted from FIRST	$16^{\text{h}} 43^{\text{m}} 11.35^{\text{s}}$	
Dec (J2000) extracted from FIRST	$+31^{\circ} 56' 18.00''$	
Redshift $z$	0.586	(2)
Total flux density $S_{1.4\text{GHz}}$ (mJy)	$112 \pm 6$	(1)
$\log L_{1.4\text{GHz}}$ ( $\text{W Hz}^{-1}$ )	26.20	
Total flux density $S_{4.85\text{GHz}}$ (mJy)	$41 \pm 7$	(3)
$\log L_{4.85\text{GHz}}$ ( $\text{W Hz}^{-1}$ )	25.76	
Spectral index $\alpha_{1.4\text{GHz}}^{4.85\text{GHz}}$	0.82	
Largest Linear Size ( $h^{-1} \text{ kpc}$ )	10.56	(5)
0.1-2.4 keV flux ( $\text{erg s}^{-1} \text{ cm}^{-2}$ )	$1.1 \times 10^{-12}$	(2)
$\log L_{\text{bol}}$ ( $\text{erg s}^{-1}$ )	$45.736 \pm 0.008$	(4)
$\log M_{\text{BH}}/M_{\odot}$	$8.43 \pm 0.07$	(4)
Eddington ratio	0.16	(4)
Projected separation of the optical components	$2.3''$	(2)

Note. Spectral index defined as ( $S \propto \nu^{-\alpha_r}$ ). References: (1) Becker et al. (1995), (2) Brotherton et al. (1999), (3) Gregory & Condon (1991), (4) Shen et al. (2010), (5) this paper.

TABLE 2  
FLUX DENSITIES OF FIRST J1643+3156 PRINCIPAL COMPONENTS FROM THE 1.66 GHz AND 5 GHz MERLIN IMAGES

Components	$S_{1.66\text{GHz}}$ mJy	$\theta_{\text{min}} \times \theta_{\text{maj}}$ arcs	$S_{5\text{GHz}}$ mJy	$\theta_{\text{min}} \times \theta_{\text{maj}}$ arcs
C	$14 \pm 0.6$	$0.13 \times 0.23$	$7 \pm 0.3$	$0.01 \times 0.02$
E	$18 \pm 0.8$	$0.22 \times 0.31$	—	—
W1	$22 \pm 0.6$	$0.13 \times 0.23$	$2 \pm 0.3$	$0.02 \times 0.03$
W2	$32 \pm 0.7$	$0.17 \times 0.31$	$3 \pm 0.3$	$0.02 \times 0.07$

ing local d-programs and AIPS-based PIPELINE procedure developed at Jodrell Bank Observatory ([http://www.merlin.ac.uk/user\\_guide/](http://www.merlin.ac.uk/user_guide/)). OQ208 was used as the point source or baseline calibrator and 3C 286 as the flux and polarization calibrator. Further cycles of phase self-calibration and imaging using the NRAO AIPS software was then used to produce the final total intensity (I) and polarization intensity (P) images. The polarization was detected only in component W2. The flux densities of the main components of the target source were then measured, by fitting Gaussian models, using AIPS task JMFIT (Table 2). The position of the optical counterpart of target source is marked with a cross in the maps and was taken from the Sloan Digital Sky Survey (SDSS/DR7).

Throughout the paper, we assume a cosmology with  $H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ,  $\Omega_M = 0.27$ ,  $\Omega_{\Lambda} = 0.73$ .

## 3. RESULTS

The 1.66 GHz MERLIN radio image of FIRST J1643+3156 shows four components of the source (Fig. 1a). A component indicated as C, which position is well correlated with the position of the optical counterpart is a radio core. We have measured flux densities of the indicated components (Table 2) and calculated spectral index for component C which is  $\alpha_{1.66\text{GHz}}^{5\text{GHz}} = 0.6$ . However, this should be treated as an approximation since it is based on the snapshot observations where some flux can be missing. For this reason we did not calculate spectral indices for weaker

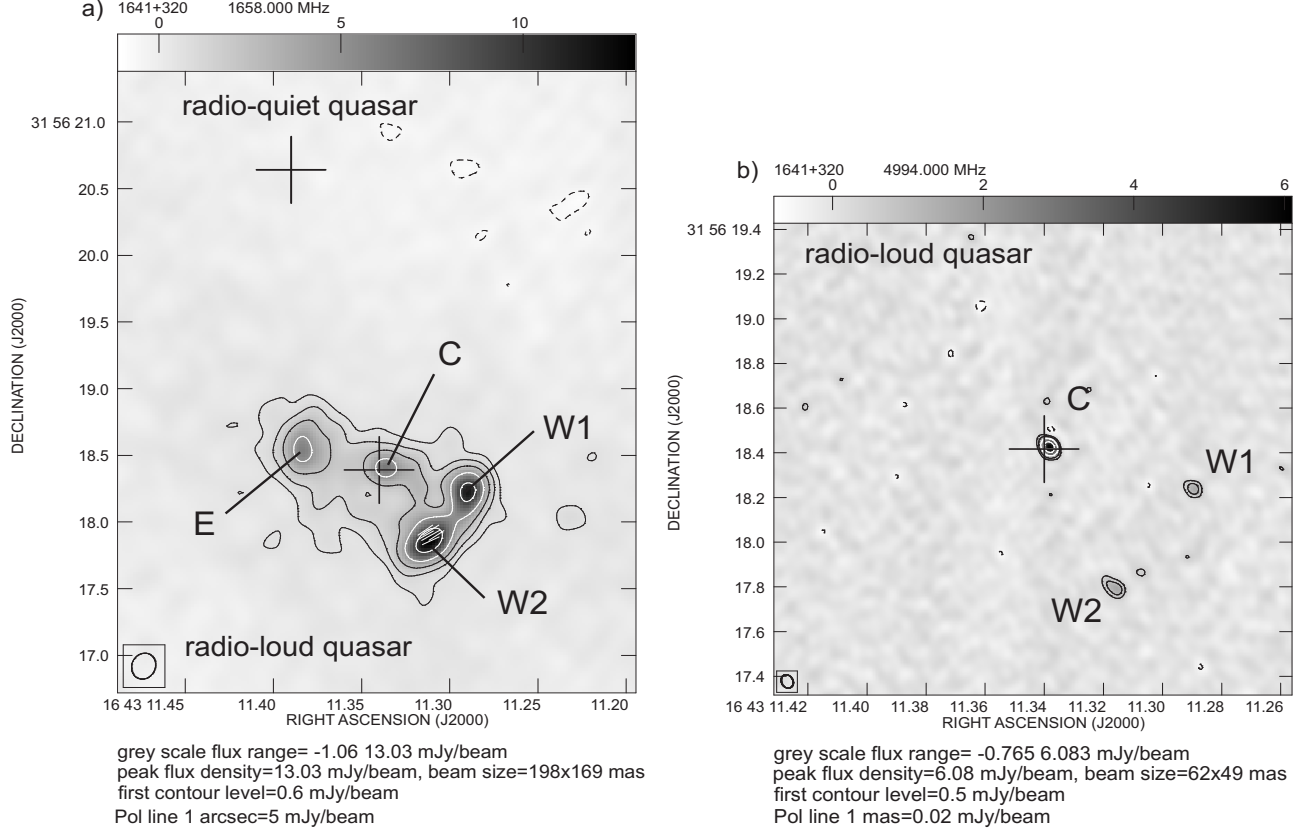


FIG. 1.— a) The 1.66 GHz MERLIN radio image, b) The 5 GHz MERLIN radio image. Contours increase by a factor 2, and the first contour level corresponds to  $\approx 3\sigma$ , vectors represent the polarized flux density. A cross indicates the position of an optical object found using the most actual version of SDSS. The shape of the beam is given in the left-bottom corner of each image.

components: the radio lobes E, W1 and W2. However, in this case the difference between the flux densities of the components at both frequencies is so large that we can assume they have steep spectra (Table 2). The lobe E is the weakest one in the 1.66 GHz image and there is no trace of it in the 5 GHz image (Fig. 1b). The 1.66 GHz MERLIN image shows that there is a connection between the component C and the south-western component W2. We suggest that this could be the most current jet direction and particle ejection. There is also an extended emission around the four compact components in the 1.66 GHz image. However, no extended emission and potential jet is visible in the 5 GHz image, and all three features detected in 5 GHz image are very weak. W2 is also the only one component showing polarization and only at the frequency of 1.66 GHz. Less than 1% of the total emission of W2 is polarized at 1.66 GHz. The polarization angle amounts to  $-59^\circ \pm 15^\circ$  (from N to E). The polarization vectors are often perpendicular to the jet direction, as in this case, suggesting that the component W2 is powered by the jet. Although the uncertainty of polarization angle is large and without more sensitive 5 GHz observations of FIRST J1643+3156, the interpretation should be treated as estimation.

Using the SDSS spectrum of FIRST J1643+3156 we have measured its emission lines widths and luminosities (Kunert-Bajraszewska & Labiano 2010). FIRST J1643+3156 has the largest [O III] luminosity ( $L_{[\text{O III}]} = 1.1 \times 10^{43} \text{ erg s}^{-1}$ ) among the Low Luminosity Compact (LLC) objects we observed and was classified

as High Excitation Galaxy (HEG). Among the LLC objects which we consider as the candidates to the short-lived radio objects population, we found three binary systems: the two galaxy pairs (0854+210, 1506+354), and quasar binary FIRST J1643+3156 (1641+320). Their morphologies are highly disrupted (Kunert-Bajraszewska et al. 2010a) and do not resemble typical CSS sources with symmetric double lobes.

### 3.1. Optical Imaging

FIRST J1643+3156 has been observed with the Wide Field Channel (WFC) of the Advanced Camera for Surveys (ACS) of the Hubble Space Telescope (HST) by Ford (2005) and described by Martel et al. (2005). The images were made in 2005 in three filters:  $g$ (F475W),  $r$ (F625W), and  $I$ (F814W), and the exposure time of the observations was  $\sim 18$  minutes in  $g$  and  $r$  band, and  $\sim 36$  minutes in  $I$  band. We have retrieved the data from the HST Archive and present the  $I$  band image of FIRST J1643+3156 in Figure 2. As described by Martel et al. (2005) the host galaxy of the radio-loud quasar is highly disturbed while the host galaxy of the radio-quiet source appears smooth and unperturbed. Three morphological features can be distinguished in the image of the host galaxy of the radio-loud quasar: a bright arc extending  $\sim 3 \text{ kpc}$  west of the nucleus, a large diffuse knot located  $\sim 8 \text{ kpc}$  to the south, and a group of filaments to the north-east of the nucleus. Distorted filaments are also observed between the radio-loud and radio-quiet quasars. We have made an overlay of the contours of the radio emission at 1.66 GHz on the optical image. We suggest

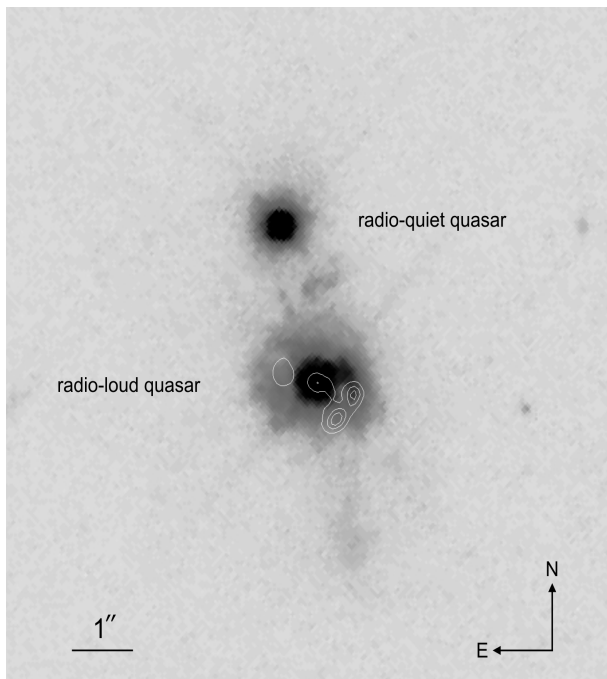


FIG. 2.— The HST/ACS image of FIRST J1643+3156 in F814W filter with an overlay of contours of the radio emission at 1.66 GHz. The two bright quasar nuclei are visible. The host galaxy of the radio-loud quasar is perturbed.

that the bright arc on the optical image corresponds to the disturbed radio structure what may indicate they are both an effect of the quasars' interaction.

#### 4. DISCUSSION

FIRST J1643+3156 belongs to the population of Compact Steep Spectrum (CSS) sources. CSS sources form a well defined class of compact radio objects ( $\leq 20$  kpc) and are considered to be younger progenitors of large radio-loud AGNs. This interpretation of the CSS class has now become part of a standard model (Fanti et al. 1995), and Readhead et al. (1996) have proposed an evolutionary scheme unifying the three classes of radio-loud AGNs: Gigahertz-Peaked Spectrum (GPS) sources, CSS sources and large scale radio objects. Two pieces of evidence definitely point towards GPS/CSS sources being young objects: lobe proper motions (up to  $0.3c$ ) giving kinematic ages as low as  $\sim 10^3$  years for GPSs (Owsianik et al. 1998; Giroletti et al. 2003; Polatidis & Conway 2003) and radiative ages typically  $\sim 10^5$  years for CSSs (Murgia 2003). Although these AGNs are small-scale objects, in some cases CSO/GPS sources are associated with much larger radio structures that extend out to many kiloparsecs. In these cases, it has been suggested that the CSO/GPS stage represents a period of renewed activity in the life cycle of the AGN (Stanghellini et al. 2005; Kunert-Bajraszewska et al. 2006). Reynolds & Begelman (1997) have also proposed a model in which extragalactic radio sources are intermittent on timescales of  $10^4 - 10^5$  years, suggesting that many young AGNs, CSS and GPS sources, might be short-lived objects. Detection of several candidates for dying compact sources (Giroletti et al. 2005; Kunert-Bajraszewska et al. 2006; Kunert-Bajraszewska et al. 2010a; Orienti et al. 2010) supports this view.

The ignition of the AGN activity can be caused by the

major merger or instabilities in the accretion flow. In the second case it is highly probable that the activity will be intermittent (e.g. Czerny et al. 2009), although this can change when considering non-standard situation, namely the binary system (see section 4.1). Observations indicate, that about 50% of young AGN contain double nuclei in their host galaxies or exhibit morphological distortions that are supposed to be due to the past merging events (O'Dea 1998; Liu 2004; An et al. 2010; Kunert-Bajraszewska et al. 2010b).

The CSS object FIRST J1643+3156 is an uncommon young AGN because of its complex radio morphology and fact, that it is a part of a binary quasar. The disturbed radio and optical structure of FIRST J1643+3156 suggests that both quasars in this system are physically bound and influence each other during the evolution cycle (Figure 2). However, there is not enough information to determine the geometry of the binary system: the full orbital velocity, radius and period, which is important in explaining the distortions in radio structure we observed. Based on the observed line-of-sight velocity difference between the binary system components ( $V = 300 \text{ km s}^{-1}$ ) and its separation ( $d = 15 \text{ kpc}$ ), we can roughly estimate the timescale of the tidal perturbation between the two quasars as  $T_p = d/V = 5 \times 10^7$  years. The age of the radio source can be estimated e.g. from the size  $l$  of the source, as  $T_a = l/v_{\text{lobe}}$ . Taking the moderate lobe velocity of  $v_{\text{lobe}} = 0.1c$  and even the largest linear size of  $l = 10.56 \text{ kpc}$  (which is a distance between peaks of components E and W1 assuming they belong to the same phase of activity), the estimated age of the source is on the order of  $3 \times 10^5$  years. Thus we consider a few scenarios which may explain the radio properties of the observed binary quasar.

##### 4.1. Intrinsic activity restart and its modulation by the companion

The first scenario is based on the conclusion that if the radio activity timescale ( $\sim 10^5$  years) is much shorter than the tidal perturbation timescale ( $\sim 10^7$  years), the radio activity of the radio-loud component does not have to be induced directly by the interaction with the companion galactic core. It could be the intrinsic mechanism that made the quasar start its activity. The radio structure E – C – W1 could be then the sign of the first period of activity which was prematurely ceased by the instability of the accretion disk (Janiuk et al. 2002; Czerny et al. 2009). The model for the internal instability in the accretion disk is based on the radiation pressure dominance. This physical effect leads to the periodic outbursts of the disk luminosity, intermittent with the low luminosity periods. The feature W2 is then interpreted as the subsequent activity phase which could be now changed due to the interaction with the companion galaxy. We have performed such modelling (see Section 4.1.2 for the full description and plots) using the accretion disk instability cycle. To account for the influence of the companion galaxy, we change the outer boundary condition in the evolutionary calculations. We assumed the accretion rate to be a periodic function of time and this perturbation is given by the tidal interaction in the period  $\sim 10^7$  years. The black hole mass was  $M_{\text{BH}} = 3 \times 10^8 M_{\odot}$ , as estimated for the radio-loud component (Shen et al. 2010). As a result we obtained that the interaction with the companion

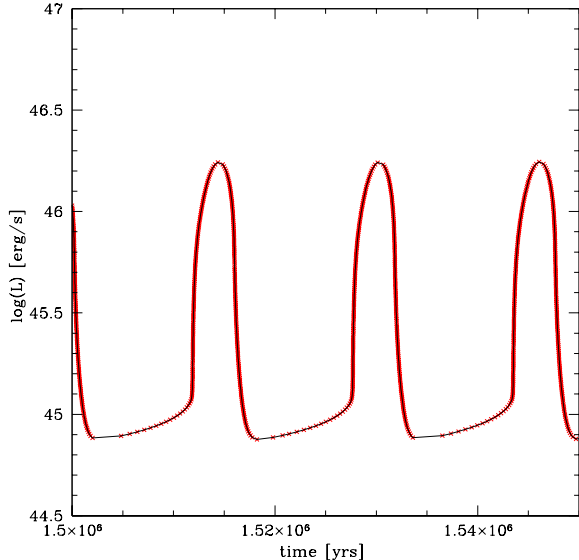


FIG. 3.— Time evolution of the active core luminosity in the cycle due to the radiation pressure instability. The black hole mass is  $M = 3 \times 10^8 M_\odot$ , external accretion rate is constant  $\dot{m}_{\text{ext}} = 0.14$  and viscosity parameter is  $\alpha = 0.01$

quasar influences the modulation and overall evolution cycle of the primary quasar. It can dramatically change the activity pattern and lead to the prolonged, up to a few million years, activity outbursts.

Below, we present the results of the numerical modeling of the intermittent activity for the binary quasar.

#### 4.1.1. Luminosity outbursts of the core of radio-loud component

In Figure 3 we show an exemplary lightcurve that results from the accretion disk instability model. The model was described in detail with appropriate time-dependent equations and numerical method in Janiuk et al. (2002).

The luminous core in our example exhibits regular outbursts for the external (mean) accretion rate of 14 per cent of the Eddington rate. The duration of the outbursts and their separation depends on black hole mass and viscosity parameter. In this case, the outbursts cycle lasts about  $2 \times 10^4$  years.

In this model, we postulate that a large fraction of the disk power at outburst is transferred to the jet and provides a source for its kinetic energy, parametrized by the fraction  $\eta_{\text{jet}}$  in the range (0;1). This jet fraction is dependent on time and radius via the local accretion rate, depending on both time and distance from the black hole:

$$\eta_{\text{jet}} = 1 - \frac{1}{1 + A_{\text{jet}} \dot{m}(r, t)^2}. \quad (1)$$

with  $A_{\text{jet}}$  being a parameter of the model. The physical meaning of this parametrization is that at the Eddington accretion limit there would be equipartition between the jet and disk radiation for  $A_{\text{jet}} = 1$ . We consider here the accretion rates well below the Eddington limit and we adopt a moderate value of  $A_{\text{jet}} = 2.5$ . The disk-jet coupling results in reducing the outbursts amplitudes in comparison to the models without the jets (Janiuk & Czerny 2011). This model is plausible for the radio-loud quasar and consistent with its observed luminosity.

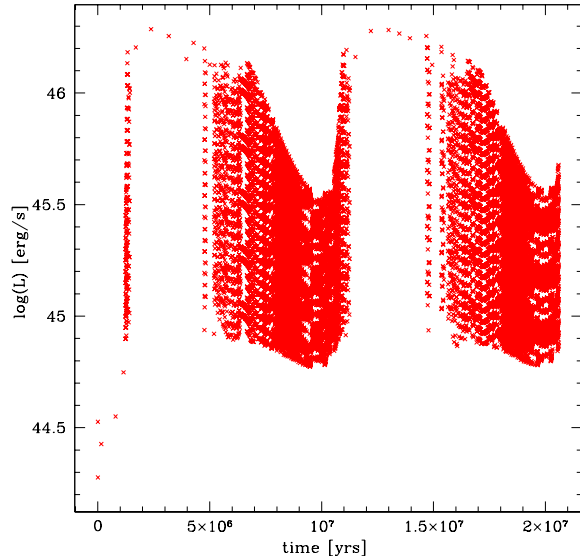


FIG. 4.— The outburst amplitudes of the radio-loud component's core luminosity in the model with the accretion rate modulation due to the binary interaction. The perturbation is parametrized according to Eq. 2, with  $T_p = 10^7$  years and  $\dot{m}_0 = 0.014$ . The viscosity is  $\alpha = 0.01$ , black hole mass is  $M = 3 \times 10^8 M_\odot$  and  $A_{\text{jet}} = 2.5$ .

#### 4.1.2. Influence of the companion radio-quiet quasar

To account for the influence of the companion galaxy, we change the outer boundary condition in the evolutionary calculations. The external accretion rate, instead of being a constant parameter, is a periodic function of time:

$$\log \frac{\dot{m}_{\text{ext}}}{\dot{m}_0} = \sin\left(\frac{2\pi}{T_p} t\right) \quad (2)$$

where  $T_p$  is a characteristic perturbation timescale. We assume that this perturbation is given by the tidal interaction and  $T_p \approx 10^7$  years. The accretion rate is parametrized by  $\dot{m}_0 = 0.014$  and changes from  $0.1\dot{m}_0$  to  $10\dot{m}_0$ , so that it never exceeds the Eddington limit during the perturbation cycle.

The modulation of the material supply rate to the outer disk edge results in periodic changes of the outburst pattern. Both the durations and amplitudes are affected.

In Figure 4 we show the modulated evolution of the unstable disk coupled with a jet. Note that the Figure 4 shows now much longer timescale than in Figure 3 and therefore the individual shorter timescale outbursts are marked as a shaded regions. The adopted black hole mass was  $M = 3 \times 10^8 M_\odot$ , starting accretion rate  $\dot{m}_0 = 0.014$  and the jet parameter  $A_{\text{jet}} = 2.5$ . Now, the pattern of the long term evolution is the following. The largest external accretion rates result in a persistent outburst state of the disk, while the luminosity fluctuations occur at small accretion rates. This long persistent high state was not obtained in the simulations with a constant boundary condition, and is an effect of the modulation. Moreover, it was not obtained in the models without the disk-jet coupling and we had persistent quiescent states instead. Also, we noted that the transition rates from the intermittent to the persistent state and vice versa, are not equal: in the present simulation,

the first transition occurs at  $\dot{m}_1 = 0.08$  and the second transition at  $\dot{m}_2 = 0.02$ . This complex behavior results from the adopted jet cooling term, which depends non-linearly on time and distance. In this way, the accretion disk plasma holds the “memory” of the past conditions as the information propagates inwards in the disk in the viscous timescale, so that we obtain an effect of ‘hysteresis’.

In conclusion, the accretion rate modulation overimposed on the cyclic outbursts influences the source behavior on long timescales. This modulation is due to the companion galaxy tidal forces, which influence the rate of matter supply to the outer regions of the accretion disk. The transitions from the strong, periodically active behavior, through the ‘flickering’, and then to the persistent high state of the source may occur due to the companion interaction.

In the quasar FIRST J1643+3156 we may therefore be observing the active core that accretes near the transition rate from the intermittent to the persistent high state. We consider here a scenario in which the radio structure E – C – W1 is a sign of the past activity, and W2 is a current activity episode that can be prolonged up to a few million years, due to the interaction with the companion quasar.

We emphasize here that the above numerical simulations give a novel result and to our knowledge such hydrodynamical instability models with a time-dependent boundary condition have not been performed before. The details of the simulations are depending also on the presence or absence of the jet or outflow from the disk and are intended to be discussed elsewhere (Janiuk et al. in preparation).

The instability scenario discussed above explains the episodic activity of the radio source (sec. 4.1.1) as well as the prolonged activity episodes due to the influence of the companion (sec. 4.1.2). In this way we accounted for the timescales appropriate for the observed source. However, because the geometry of the structures observed is also complex and the instability scenario itself is not able to predict geometrical changes (the non-colinearity of the observed structures), below we discuss further possibilities.

#### 4.2. Geometry changes due to the interaction with the companion

The intermittent radio activity can be caused by an intrinsic mechanism, as well as modulated or directly triggered by the interaction with the companion galaxy.

##### 4.2.1. Precession

The observed complex radio structure of FIRST J1643+3156 could be then caused by the accretion disk precession due to tidal torques induced by the companion in the binary system (Caproni et al. 2006). In this case, the precession due to the tidal interaction in a binary system will occur if the binary orbit is not coplanar with the accretion disk. Considering this scenario the disturbed radio morphology can be explained in the following way. The structure E – C – W1 is the first episode of the radio source activity and the first direction of the radio jet and particle ejection. Then the precession caused the change in the accretion disk plane and the new jet direction of

FIRST J1643+3156 is the south-western one - the jet is fuelling the component W2. This precession scenario is therefore independent but also complementary to the episodic activity scenario discussed above in Sec. 4.1, as it explains the lack of colinearity between the subsequent structures (to account simultaneously for both effects, i.e. the timescales and geometry changes, would require essentially 3D time-dependent global modeling of a non-axisymmetric unstable accretion disk, which is beyond the scope of the present work). The estimated age of the radio structure of FIRST J1643+3156 is on the order of  $10^5$  years. The timescale of the decay of the components no longer powered by the jet (lobes E and W1 ?) is comparable with the timescale of its activity phase. However, during the first few periods of inactivity, the radio luminosity fades rapidly (Reynolds & Begelman 1997) making the potential distortions well visible only during a short period of time. The fading source structure is then characterized by weak emission detectable only in deep, low-frequency observations. It is possible then that the radio observations of FIRST J1643+3156 were made just in time to detect the distortions at lower 1.66 GHz frequency.

##### 4.2.2. Jet-ISM interaction

Finally, we consider a scenario in which the radio activity of the FIRST J1643+3156 has been directly triggered by the interaction with the companion galaxy but its radio structure is a result of the jet interaction with the host galaxy environment. The 1.66 GHz image of FIRST J1643+3156 (Fig. 1a) shows a diffuse radio emission around the radio-loud quasar suggesting very dense medium of the host galaxy of the source and indicating strong interactions. Simulations of colliding disk galaxies (Barnes & Hernquist 1996) tracked the evolution of both gas and stars in the merger during the subsequent orbital loops. The gas accumulates in the nucleus of each galaxy as the two orbit away from each other, but stronger perturbation of the incoming galaxies are visible only after the first pericentric passage. In such an environment, a black hole may undergo many fuelling events and each event may completely disrupt and/or restart the jet. After each renewal, the jet may need to force its way through the changing nuclear environment anew. In the case of FIRST J1643+3156, the features W1 and W2 could be parts of the same jet. The jet is changing its orientation during propagation in the central regions of the host galaxy due to interactions with the dense environment. The feature E could then be the counter-jet. The presence of strong [O III]  $\lambda 5007$  in FIRST J1643+3156 (Brotherton et al. 1999; Kunert-Bajraszewska & Labiano 2010) suggests the jet-ISM interactions. According to Labiano (2008), the expansion of the radio source through the host ISM could be triggering or enhancing the [O III]  $\lambda 5007$  line emission through direct interaction. The presence of the cold accreting material could be responsible for even higher gas excitation, and consequently for higher [O III]  $\lambda 5007$  line emission. It has been discussed by Buttiglione et al. (2010) that the High Excitation Galaxies (HEGs), like the FIRST J1643+3156, are powered by accretion of cold gas provided probably by the merger with a gas rich galaxy.

## 5. SUMMARY



FIRST J1643+3156 is an unusual and statistically very rare, low redshift binary quasar. The radio morphology of FIRST J1643+3156 is complex on both frequencies and consists of four components which indicates rapid change of jet direction and/or restart of the jet. The host galaxy of the radio-loud quasar is also highly disturbed and we suggest that the first pericentric passage took place in this pair igniting and/or changing the radio activity and morphology in the radio-loud component. We discussed several possible scenarios that could explain such a complex radio morphology: (i) accretion disk instability, modulated by the interaction with the companion, (ii) precession of the disk/jet due to the companion's tidal forces and (iii) jet-cloud interactions.

New observations could test the evolution scenarios presented here. A more sensitive radio observations may allow to trace the jet pattern and the change of its direction at both 1.66 GHz and 5 GHz frequencies. An infrared and X-ray observations could give us information about the intrinsic absorption and potential presence of the dense environment in FIRST J1643+3156.

Based on the analysis described above we suggest that regardless of the mechanism that caused the distortions of the radio structure visible in the binary system, they may be short-lived phenomena. The disturbed radio components that are no longer powered by the jet can quickly fade away. This makes the potential distortions detectable only during a short period of time and implies a low detection rate. To speculate what could be

the past and future history of FIRST J1643+3156 binary system, we performed numerical simulations concerning the influence of the companion quasar to the activity of the radio-loud one. The results show that the ignited or subsequent activity phase can be prolonged up to a few million years and limits the occurrence of distorted radio structures, at least those caused by the internal instability in the accretion disk.

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